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POTATO TUBER DISEASES
Management Before and After Harvest

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POTATO TUBER DISEASES

Management Before and After Harvest

Contents

Author

Randall C. Rowe
Professor of Plant Pathology and Extension Specialist
Department of Plant Pathology
The Ohio State University
Ohio Agricultural Research and Development Center
Wooster 44691

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CAUSES OF POTATO TUBER DISEASES

Introduction

Postharvest diseases of potatoes are a major problem for many growers. Too often, excellent crops in the field are drastically reduced by rotting in storage. The process of transforming a healthy crop to one of poor quality is primarily caused by the activity of two types of microorganisms—bacteria and fungi. In addition, tuber responses to direct injury can result in lower quality even in the absence of these rot-causing microorganisms.

Bacteria

Of the two types of microorganisms, bacteria are more aggressive, and they usually cause the most serious storage losses. Bacteria cause foul-smelling, slimy soft rots and black leg, ring rot and pink eye. Bacteria are microscopic, single-celled organisms; they can occur in tremendous numbers because of their ability to reproduce rapidly. Under favorable conditions, a bacterial cell can reproduce by dividing every 30 minutes. Through this process, a cell may yield 15-20 million cells in only 12 hours.

Because of their small size and large numbers, bacteria can spread easily over long distances via contaminated soil, water, machinery, tubers or burlap bags. They also can move readily between tubers in storage via the flow of slimy ooze from rotting potatoes.

Growth and reproduction of bacteria are favored by warmth and moisture. When potatoes are kept dry and at temperatures below 45°F, little rot occurs because bacteria cannot reproduce rapidly. Bacteria also require wounds or natural openings to gain entry into tubers. These characteristics can be utilized in the management of stored potatoes to minimize bacterial decay.

Fungi

Fungi are responsible for tuber diseases such as fusarium dry rot, late and early blight, pink rot and pythium leak. The fungi responsible for these diseases commonly occur in soil and are virtually unavoidable. Fungi grow as a network of fine threads called "mycelia," which usually arise from the germination of spores. Mycelia infect tubers by entering through the skin and growing throughout the tissues. Entry is made easier through wounds and enlarged lenticels but also can occur directly. As with bacteria, growth of fungi is favored by warmth and moisture, and this fact can be exploited in disease management.

Injury

Injury to tubers is the primary factor in infection by microorganisms. Mechanical injury, primarily at harvest, is the most important type of injury. Freezing injury also can be significant. "Field frost" at harvest often is followed by bacterial infection, which then may develop further in storage. Fungal tuber infections, especially late blight, usually are associated with with secondary soft rot bacteria. Both bacteria and fungi also can enter tubers through lenticels—small, natural openings scattered across the surface of the tuber (Figure 1). These openings enlarge when soil moisture is high and thus provide easy entry sites. Because of this, preharvest tuber rot commonly occurs in wet soils.

MANAGEMENT STRATEGIES TO MINIMIZE TUBER DISEASES

Control of potato tuber diseases is a season-long process that begins with the selection of cultivars and planting sites and extends through harvest into storage management to control postharvest decay.

Cultivar Selection and Site Preparation

Several decisions affecting tuber disease management must be made by potato growers prior to planting. Use of certified disease-free seed is the first step in production of a healthy crop. Cultivar selection is the next important choice. Potato cultivars vary in susceptibility to diseases such as scab *(Streptomyces scabies)* (Figure 9) and late blight *(Phytophthora infestans)* (Figures 2, 3) and physiological disorders such as hollow heart (Figure 18) and internal necrosis (Figure 14). For this reason, avoidance of highly susceptible cultivars is important, particularly when a grower anticipates a specific disease problem based on past experience.

Site selection and preparation also are important in tuber disease management. Adequate soil drainage is criticial in order to avoid preharvest decay by tuber-rotting organisms favored by wet soils. A 2- to 3-year crop rotation scheme is advisable to minimize populations of soil-borne pathogens. Avoid using crops such as sunflower and raspberry and solanaceous crops such as tomato, pepper and eggplant. These crops may favor organisms that cause potato diseases. Rotation alone will not control most soil-borne pathogens, but it is an important component of disease management.

Rotation also has significant advantages in controlling weed and soil insect pests and in managing soil structure and fertility. Steps should be taken to maintain or improve soil structure and minimize soil compaction, because these factors can have considerable effect on tuber development and harvest injury. Soil clods are a significant source of harvest injury and often result from improper tillage practices earlier in the season or during the previous season.

It has long been recommended that the pH of potato production soil be maintained below 5.5 for scab control. Although acid-tolerant strains of *S. scabies* have been reported, the recommendation remains generally valid. The addition of animal manure to soil used for potato production should be avoided because it may greatly favor scab development.

Nitrogen fertility also is a consideration in tuber disease management. Insufficient nitrogen during tuberization and later plant development can increase susceptibility of foliage to early blight *(Alternaria solani)*, which can infect tubers (Figure 4). Insufficient nitrogen also can hasten the development of verticillium wilt, which can cause stem-end vascular necrosis. On the other hand, excess nitrogen can produce extensive overgrowth of foliage, resulting in a protected, moist microclimate at the soil level, especially under irrigation. These conditions favor the development of bacterial soft rot and blackleg *(Erwinia cartovora)* (Figures 12, 13). Excess nitrogen also can delay maturity, resulting in more skinning and harvest injury.

Seed Potato Handling and Storage

Proper handling of seed potatoes prior to planting is an essential step in disease management. Growers should inspect seed on receipt and should reject any lot with visible frost injury or with extensive scab or *Rhizoctonia* sclerotia on the surface. Tubers also should be checked for fusarium dry rot (*Fusarium* sp.) (Figures 7, 8). Thiabendazole treatment of seed potatoes prior to shipment has been useful in dry rot control, but new infections may begin at wounds that occur during handling and shipping.

Growers often must store seed potatoes for 6-8 weeks prior to planting. Seed in burlap sacks should not be stored more than two pallets high, and space must be allowed for adequate aeration. All storage areas should be disinfested prior to receipt of seed potatoes to minimize contamination from pathogens associated with previous crop residues. Seed should be held below 45°F but above freezing (32°F). Seed should be allowed to warm above 55°F only just before the cutting operation.

Cutting of seed pieces from whole "A-size" tubers is a prime point in the production cycle for spread of tuber-borne pathogens, particularly ring rot and soft rot bacteria. Seed-cutting equipment should be thoroughly disinfested before use and again between each seed lot to avoid potential cross-contamination.

After cutting, seed pieces should be dusted with a fungicide formulated for that purpose. Studies in Ohio have shown that improved emergence following seed treatment does not occur every year. However, the practice is beneficial in years when weather conditions are unfavorable for rapid emergence during the 4-6 weeks following planting.

After fungicide treatment, cut seed should be held at 55°F, with good air movement through the seed piece pile to hasten the healing process.

Some growers cut seed pieces and plant immediately. This works well if soil temperatures are in the 55-65°F range so that healing can proceed rapidly in the soil. In cold, wet soil, unhealed seed pieces are more likely to rot prior to germination. The use of uncut, "B-size" seed tubers avoids the risks of seed cutting and eliminates the need for healing procedures. However, higher cost and horticultural considerations often preclude the use of whole seed.

Planting

The planting operation also has disease management implications; an important one is the use of the pick-type planter. After puncture of an infected seed piece, tuber-borne bacteria, such as those causing ring rot and blackleg, can be spread via a contaminated pick to the next 40-50 seed pieces. Cup planters, in which the seed pieces are carried in small cups and are not punctured, will eliminate this risk.

To promote quick emergence, planting should be delayed until soil temperatures are above 55°F. Planting in cold soil leads to slow emergence and usually poor stands because of seed-piece decay.

Depth of planting also is a factor in emergence. Shallow planting—at 2-3 inches rather than 5-6 inches—will result in quicker emergence and less stand loss to rhizoctonia stem canker. *Rhizoctonia solani* attacks emerging sprouts and may girdle and kill the sprouts before they emerge. Once emergence has occurred, stems are much less susceptible.

Control of Foliar Diseases

During crop development, two foliar diseases—late blight and early blight—are of primary importance. The late blight fungus *(Phytophthora infestans)* must survive the winter as mycelium in infested potato tubers left in the soil or cull piles. Or, it must be reintroduced in contaminated seed potatoes. Sporangia are produced during periods of cool, damp weather, and infection of foliage occurs under these conditions. Although late blight does not appear in a given field or area every year, its destructive potential demands that growers provide protection for their crop.

Early blight *(Alternaria solani)* is universally present where potatoes are grown. This fungus can live on infested plant debris in or on the soil surface, and it can form spores over a fairly wide range of temperatures. Potato foliage increases in susceptibility to *A. solani* as it matures. The name thus is a misnomer, because symptoms rarely develop until after flowering.

Both early blight and late blight can infect tubers (Figures 2, 3, 4) and must be controlled by timely application of protectant fungicides with aerial or ground equipment. Thorough coverage of plant surfaces is essential, because control is protective.

Certain cultural practices during the growing season impact directly on tuber disease management. Hilling of vines, although done primarily to protect tubers from greening due to sunlight, also can protect tubers from late blight infection. This occurs when *P. infestans* sporangia wash from leaves into cracks in the soil and come into contact with tubers. Burying the tubers 4-6 inches below the soil surface provides an effective barrier to infection.

Irrigation scheduling also can be a factor in tuber disease management. Avoidance of moisture stress during tuberization can minimize scab development. Overirrigation can favor the development of foliar diseases, especially late blight and blackleg, and tuber rots such as pink rot and leak (Figure 5, 6). Uneven moisture can aggravate abiotic tuber disorders such as hollow heart and second growth. A light irrigation just prior to harvest can reduce harvest injury from soil clods if soil is dry.

Harvest

Harvesting the potato crop involves many decisions affecting tuber disease management. The first step in the harvest process usually is the application of a herbicide to kill the vines. If insect and disease pests are managed properly and fertility is optimal, vines usually are still vigorous at harvest time and the use of chemical vine-killers is essential. Because rapid vine-killing can cause stem-end discoloration, especially if temperatures are high and the soil is dry, two split-applications of vine-killers may be desirable.

Vines must be dead for at least 1-2 weeks before harvest to ensure that tuber skins are mature so that harvest injury is minimized. Harvest wounds on tubers are the major entrance sites for soft rot bacteria and fusarium dry rot pathogens. Another reason vines must be dead at harvest is to eliminate viable *P. infestans* sporangia remaining on green foliage that could be spread to tubers during harvest and cause late blight infection in storage. Because of this, application of fungicides should continue after vine-killer is applied until vines are dead.

Steps must be taken during harvest to minimize bruising and wounding of tubers, which can lead to decay in storage. Environmental factors that affect bruising are temperature and the condition of the soil and tubers. Very wet soil conditions require excess chain agitation to separate the tubers, while heavy, dry soil can form into clods that damage tubers when carried through the harvester. Soil moisture conditions of 60-80% field capacity are optimal for harvest.

The hydration or crispness of the tubers also is a factor. Hydrated tubers are more susceptible to shatterbruise (Figure 15). Dehydrated tubers are more susceptible to blackspot (Figure 16).

Temperature also has a great effect on bruising. Generally, damage increases as tuber temperature decreases. Because of this, starting the harvest earlier in the season can reduce overall tuber injury. During cold weather, delaying the start of the harvest for several hours in the morning can have a significant effect in reducing injury. As a general rule, tuber pulp temperatures should be above 45°F before harvesting begins.

Improper harvester operation is a major cause of bruising during harvest. Reducing excess tuber agitation, rollback and drop is the primary concern. Chain surfaces should be rubber-covered, and ample padding should be placed on deflectors, sharp points and any place tubers are likely to impact. Adjust the blade deep enough so that potatoes will not be bruised or cut and to maintain a cushion of soil as far up the primary chains as possible.

A proper forward-speed/chain-speed ratio must be maintained to keep chains completely filled with potato tubers to avoid injury from bouncing and rolling. If yield is insufficient to fill the chains, growers should consider the use of a windrower in conjunction with a two-row harvester, so that four rows will go over the chains at once.

Machinery should be adjusted to avoid sagging and whipping of the chains and to minimize drops so that tubers never fall more than 6 inches. Beds of bulk trucks used to receive tubers from the harvester also should be padded, especially the side where the tubers first land. Adjust the conveyor to ensure only short drops into the truck.

Grading and Storage

Clean and sanitize storages before receiving potatoes. Check all monitoring instruments and ventilation systems. Make sure fans run and ducts are free of obstructions. Be sure storages are well-insulated to avoid chilling injury. If excessive storage rot, and especially ring rot (Figure 10, 11), occurred in the previous crop, storages should be completely disinfested according to proper procedures.

Use care when unloading bulk trucks. All drops should be padded. Grading into storage should be considered especially if a significant amount of tuber rot has occurred in the field. In this case, it is best to avoid harvesting low, wet spots in fields.

Eliminating "leakers," as well as soil, stones and other debris on the conveyor line, will aid in establishing a healthy pile for winter storage. Eliminating excess soil residue and other debris will improve air movement in the pile.

To control fusarium dry rot development in storage, many growers apply thiabendazole as a mist over the tubers as they fall onto the bin piler. As potatoes are piled for storage, the bin piler should be operated so that tubers fall no more than 6 inches and do not roll excessively. Tubers should not be piled more than 15-20 feet deep to avoid pressure bruise.

Regardless of precautions, some harvest injury will occur. A curing period is mandatory to promote suberization of wounds on tuber surfaces. "Suberization" is the process by which potato tubers seal wounds by depositing a waxy substance into cells adjacent to the wound. This transforms the surface of the damaged area into a corky tissue. During the curing period, humid air (95% RH) at 50-60°F must be moved constantly through the pile for 1-2 weeks. However, the storage environment must be monitored carefully to avoid formation of free moisture on tuber surfaces. This can result in anaerobic conditions inside the tubers, inhibiting suberization and favoring the development of some soft rot bacteria.

Once wound suberization has occurred, storage temperatures of fresh-market potatoes can be lowered to 38-40°F, which greatly retards development of tuber pathogens. With processing potatoes, temperatures must be maintained slightly higher at 45-55°F, depending on cultivar and type of processing, to avoid sugar development during storage. This makes storage for processing, especially chipping, more difficult, because tuber rot can proceed much more rapidly at the higher temperatures.

During storage, it is important to provide good air movement through the pile to supply sufficient oxygen for tuber respiration and to remove heat. Oxygen starvation can result in the development of internal blackheart (Figure 17). Humidity must be monitored closely to keep it above 90% to prevent excessive dehydration while avoiding formation of free water on the tubers. Growers should monitor the pile closely for visible wet spots or slumping areas or unpleasant odors—the signs of decay developing within the pile. If this occurs, humidity in the forced air should be lowered, the pile opened and the potatoes quickly graded and marketed.

Disposal of infected tubers must be done with future crops in mind. Under no circumstances should cull potatoes be dumped outside in piles. Cull piles are notorious sources of late blight sporangia that form in the spring on sprouts of surviving tubers. In northern areas, where freezing is ensured, it is safe in fall and mid-winter to spread tubers sparingly on fields that will not be used for potato production the following year. In other cases, cull tubers should be buried at least 6 feet deep or taken to a landfill.

When removing potatoes from storage for marketing, the temperature should be raised slowly so that the pulp temperature of tubers is above 50°F before handling. Handling cold potatoes can result in development of shatterbruise or internal blackspot. Operate bucket loaders and conveyors to minimize bruising. Corners and sharp points should be padded, and all drops should be kept to less than 6 inches. Packing line flow should be constant and filled to operating capacity. Fresh water should be used if tubers are washed before packing. Never recirculate wash water. Tubers then must be thoroughly dried before bagging to avoid soft rot development during marketing. Use well-ventilated bags and handle carefully to avoid bruising.

DESCRIPTIONS OF POTATO TUBER DISEASES AND THEIR CONTROL

Tuber Diseases Associated with Foliar Fungal Infections

Late Blight

Symptoms

Infected tubers have irregular, slightly sunken, purplish-brown lesions, often concentrated on the upper surface (Figure 2). When cut, a copperish-brown discoloration is visible that appears granular in texture (Figure 3). The infection starts just below the skin and usually penetrates only ¼-½ inch deep. When the disease develops without complications—such as through mechanical damage to tubers, high temperatures or rainy weather—the tuber symptoms are quite distinctive, showing brown, dry, sunken lesions. The slimy "wet rot" associated with late blight occurs in the field or in storage only when secondary bacteria follow the late blight infection.

Cause

The fungus *Phytophthora infestans.*

Development in Field

Tuber infections occur when spores formed on foliage wash into the soil through cracks and germinate under moist conditions. Infections usually occur on the upper portions of tubers near the soil surface. This fungus, unlike most, cannot grow and reproduce when separated from a living host plant. It may remain alive and infectious in the soil for a few weeks under cool, moist conditions, but it can persist for longer periods only in living, infected potato tubers.

Development in Storage

The late blight fungus alone produces a dry rot of the potato tuber that usually will not spread in storage. However, infected potatoes will break down quite easily, because they are usually also infected with bacteria that cause soft rot. The resulting watery rot will spread in storage. A large number thus can endanger the entire storage.

Control

1. Use certified disease-free seed potatoes.
2. Protect foliage with fungicides and continue applications until vines are completely dead.
3. Use adequate hilling to keep tubers well below the soil surface.
4. Delay harvest until all vines are completely dead to prevent contamination of tubers with foliar spores.
5. Grade into storage if significant blight is present.
6. Store at 38-40°F if significant blight is present.

Control (cont.)

7. Dispose of blighted tubers properly. Blighted tubers that survive the winter and sprout the following spring are a major source of spores. Blighted potatoes should not be dumped into cull piles, because some tubers will be protected from freezing. Spreading infected potatoes sparingly on the surface of fields not intended for potato culture the following spring and allowing the potatoes to freeze is the safest disposal method. Blighted potatoes left in the ground may sprout the following spring and produce spores, especially if the winter is mild or there is heavy snow cover. Proper application of a systemic sprout-inhibitor in summer will eliminate sprouting of volunteer plants the following spring and can have considerable value in reducing sources of early season infection.

Early Blight

Symptoms

Surface lesions on tubers appear slightly darker than the healthy skin. They usually are slightly sunken and are circular or irregular in shape. They vary in size up to ¾ inch in diameter. There usually is a well-defined and sometimes slightly raised margin between healthy and diseased tissue. Internally, the tissue shows a brown to black, corky, dry rot, usually not more than ¼-⅜ inch deep (Figure 4). Deep cracks may form in older lesions under some conditions.

Cause

The fungus *Alternaria solani.*

Development in Field

The fungus can survive for long periods in soil in infected plant debris and form spores at the soil surface. Resulting foliar infections are the source of many new spores that may wash down and infect the tubers. Field infection often occurs at harvest when spores from foliage contact tubers during digging. Immature tubers are more susceptible, but infection of mature tubers occurs readily through injuries. Early blight lesions are less prone to secondary bacterial infections than other fungal types.

Development in Storage

Under moderate temperatures (55-60°F) and high moisture conditions in storage, spores on tuber surfaces can germinate and incite infections. However, under dry storage conditions, infection is minimized, and spread to unbruised tubers is unlikely. Disease development in storage will continue if temperatures are kept at 55-60°F but will cease below 40°F.

Control

1. Maintain adequate nitrogen fertility and avoid stresses on growing plants.
2. Protect foliage with fungicides.
3. Delay harvest until vines are completely dead to allow for tuber skin maturity.
4. Avoid bruising tubers at harvest.
5. Use adequate ventilation in storage and hold at 50-60°F for 1-2 weeks to allow suberization of wounds.

Fungal Tuber Diseases

Pink Rot and Leak

Symptoms

Leak and pink rot are tuber rots that are extremely watery in nature. The water usually is held in the tissues until pressure is applied. Then, a clear to yellow, odorless liquid is given off. Infected external tissues appear turgid and may show brown shades of discoloration, especially about the eyes and lenticels in white- or dark-skinned tubers. Upon cutting, infected internal tissues are spongy and appear creamy at first, then they darken within a few minutes, finally becoming black (Figure 5). In the case of pink rot, infected tissues turn salmon-pink before becoming brown then black, and a sharp, dark margin usually sets off diseased tissue from healthy tissue (Figure 6). There is no discernible fungus growth externally or internally. Occasionally, a shell of unrotted flesh will be left near the skin, and at other times, the entire tuber will disintegrate in the soil.

Cause

The fungi *Phytophthora erythroseptica* (pink rot) and *Pythium* sp. (leak).

Development in Field

Both fungi are common in soil. Tubers become contaminated in the field, and during warm, wet weather, infection takes place through wounds that may not be visible. Pink rot infection often occurs through the stolon. Often, tubers harvested from fields on a particular day when temperatures were above normal will show leak in storage. Tubers harvested on other days will be disease-free. When temperatures are between 60-90°F, lesions become visible within 36 hours after infection. Often, soft rot bacteria may enter and check the growth of either fungus while producing a foul-smelling soft rot of their own.

Development in Storage

Under high moisture conditions, with temperatures above 40°F, development of both diseases is rapid in storage. "Leaky" tubers will drip down on surrounding tubers, and disease can spread rapidly. Often, soft rot bacteria also are present, and more often than not, that is the disease that spreads most rapidly in storage. With high air movement through the pile, infected tubers rapidly dry and shrivel, no longer endangering the remaining tubers.

Control

1. Provide proper field drainage and avoid harvesting low spots in wet seasons.
2. Avoid bruising tubers at harvest.
3. Grade into storage if significant infection is visible.
4. Provide adequate air flow through the pile.
5. Hold tubers at 50-60°F only long enough to allow suberization, then decrease temperatures to 38-40°F. Do not store at chip-stock temperatures (55°F) if significant disease is present.

Figure 1. Enlarged tuber lenticels.

Figure 2. Late blight.

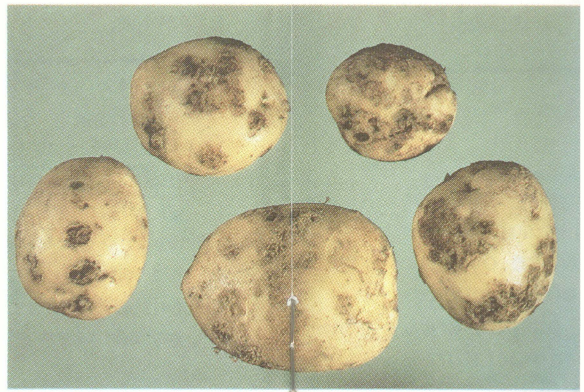


Figure 9. Scab.

Figure 3. Late blight (interior).

Figure 8. Fusarium dry rot (interior).

Figure 11. Ring rot.

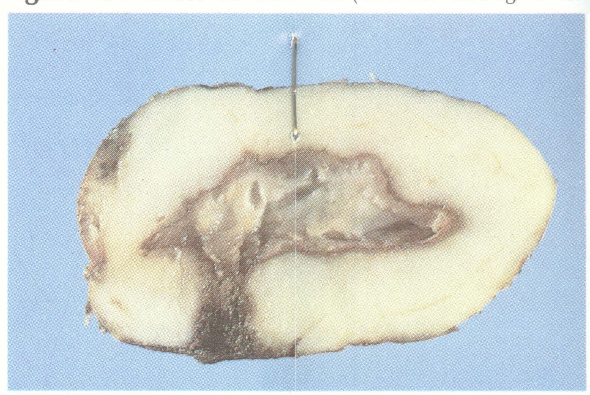
Figure 4. Early blight.

Figure 7. Fusarium dry rot.

Figure 5. Pythium leak.

Figure 6. Pink rot.

Figure 13. Bacterial soft rot (infection through wound).



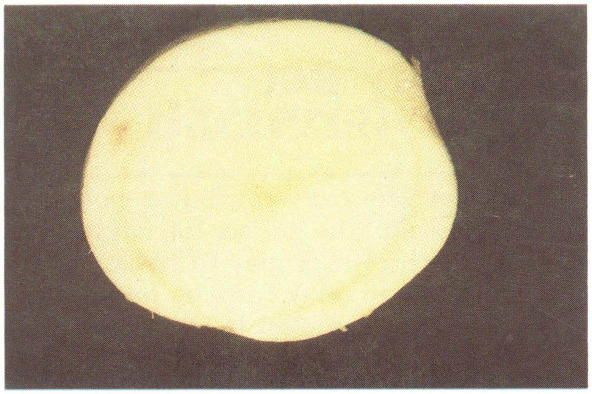


Figure 10. Ring rot (interior).

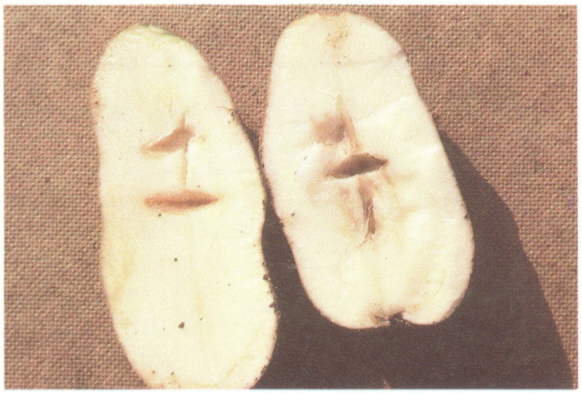


Figure 18. Hollow heart.

Figure 11. Ring rot.

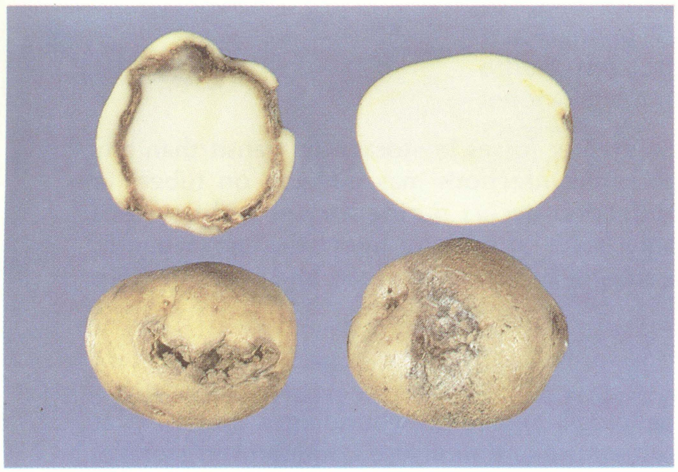


Figure 17. Blackheart.

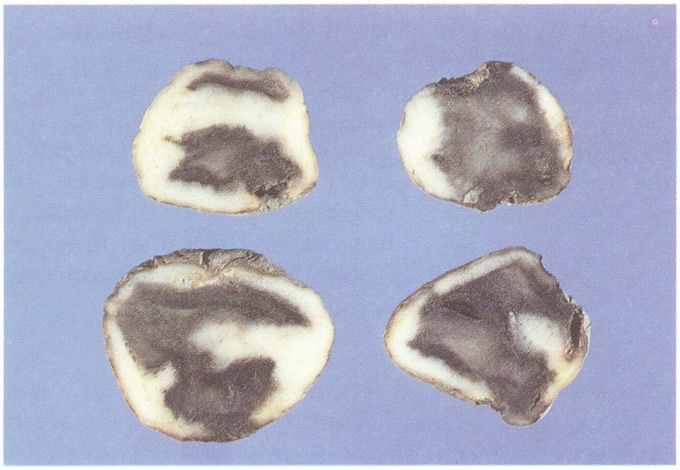


Figure 12. Blackleg (infection through stolons).

Figure 16. Internal blackspot.

Figure 14. Internal necrosis.

Figure 15. Internal shatterbruise.

Fusarium Dry Rot

Symptoms

Infected tubers usually develop a dry rot, but a moist rot also may occur if bacterial infections are involved. The surface of infected tubers is sunken or wrinkled and rotted tissue is brown or gray to black (Figure 7). White or pink growths of fungi may be visible on outer surfaces. Internal cavities often develop that contain white, yellow or pink molds. In storage, blue, black, purple, gray, white or pink spore masses may develop in the cavities. Often, at low temperatures, internal tissues will become firm and dry or even powdery (Figure 8).

Cause

Many species of the fungus *Fusarium*.

Development in Field

Fusarium tuber rots probably cause greater losses in storage or transit than any other postharvest diseases. Although some infections may develop on tubers in soil, causing stem-end decay, most infection occurs during harvest and develops in storage. The causal fungi commonly occur in soil and infect through wounds. Rough handling at harvest usually results in infection by fusarium spores that are present in most soils.

Development in Storage

Because spores usually are present in soil, and some wounding is inevitable at harvest, infection is regulated by temperature and moisture conditions in storage. Rapid suberization at 55-60°F will quickly heal wounds and prevent infection. If not properly suberized, infection is likely to occur. Infection proceeds fairly rapidly at chip-stock storage temperatures, but it will cease as temperatures drop to 40°F. However, at these temperatures, the fungus is simply dormant and will resume growth when tubers are warmed. This disease generally does not spread in storage if potatoes are properly suberized, unless a wet, soft rot is associated. Soft rot will spread in storage.

Control

1. Harvest tubers from dead vines to ensure maturity of skins.
2. Take all precautions at harvest to minimize bruising.
3. Hold newly harvested potatoes at 55-65°F with 90-95% RH for the first 1-2 weeks to promote wound healing.
4. Consider the use of thiabendazole fungicide by misting unwashed tubers as potatoes are going into storage.

Bacterial Tuber Diseases

Scab

Symptoms

Common scab is characterized by raised, tan to brown, corky areas, varying in size and shape and scattered on the surface of infected tubers (Figure 9). On thin-skinned varieties, the scabby areas frequently are pitted or pocked. On others, the scabby areas may be raised. There is no true rot associated with the lesions, and injury usually is superficial, although it can be up to ½ inch deep. Common scab should not be confused with white, enlarged lenticels that frequently occur on potatoes harvested from wet soil (Figure 1).

Cause

The actinomycete *Streptomyces scabies.*

Development in Field

The scab organism is widespread in soil, but it usually is confined to localized areas and fields. It is distributed from field to field chiefly on infected tubers and in wind- and water-borne soil. It may survive passage through the digestive tract of animals and become distributed with manure. Young tubers are most susceptible to infection. The pathogen can infect through lenticels or injury from soil insect feeding. Very young pea-sized tubers are highly susceptible and may be infected without injury. Deep scab may be accentuated by soil insect feeding activity. Scab generally is most severe under warm, dry conditions and can be somewhat alleviated by irrigation during tuberization.

Development in Storage

Mature tubers are not susceptible, and thus further infection does not occur in storage.

Control

1. Plant scab-free seed stock.
2. Rotate potato crops with grain or grass. Especially avoid carrots, beets and radishes, and avoid directly following potatoes where scab was a problem.
3. Maintain soil at pH 5.5 or slightly below.
4. Plant less-susceptible cultivars if available and adapted to local conditions. Cultivars possessing some tolerance include Superior, Shurchip, Norchip and Norland, as well as most russet-skinned varieties. Those especially susceptible include Denali, Katahdin and Monona.
5. If irrigation is available, do not allow soil to become dry at tuber setting time.
6. Do not apply manure to fields.

Ring Rot

Symptoms

The first sign in tubers, when cut at the stem end, is a light-yellow vascular discoloration that becomes brown with age (Figure 10). By sqeezing the tissue around the cut surface, a creamy yellow or light brown, odorless, cheesy exudate will ooze out. In advanced cases, complete breakdown of the vascular ring will be evident, with cavitities extending to the pith and cortex (Figure 11). Advanced lesions may become dry and powdery, or soft rot bacteria may invade the tissue. In advanced cases, the exterior surfaces of the tuber above the lesion may show skin cracks and appear slightly sunken (Figure 11). Early tuber symptoms are difficult to diagnose conclusively and must be confirmed by laboratory tests.

Cause

The bacterium *Corynebacterium sepedonicum.*

Development in Field

This bacterium lives from season to season chiefly in tubers. Even if exposed to below-freezing temperatures, it will survive in dried slime on crates, bins, burlap sacks or harvesting and grading machinery. It generally does not persist in soil more than one year, but it can survive in tubers that overwinter as volunteer plants. It is spread by cutting knives and contaminated planting machinery and also by irrigation water. Infection of tubers occurs through wounds during cutting or planting, but plant infection also can occur in soil through wounds in stems, roots or stolons. Bacteria become systemically established throughout infected plants in the vascular tissues, and developing tubers will become infected.

Development in Storage

Infected tubers with no visible symptoms at harvest may develop symptoms during storage, especially if kept above 50°F. There generally is little, if any, spread of ring rot among tubers in storage. However, advanced infections may be contaminated with soft rot bacteria, and these tubers may break down completely in storage, spreading soft rot to adjoining tubers.

Control

1. Plant foundation or certified disease-free seed stock. There is no tolerance for ring rot in certified seed stock.
2. When cutting seed, cutters should be periodically cleaned and disinfested. Under no circumstances should a seed lot change be made without cleaning and disinfesting cutters.
3. Store seed potatoes in clean, disinfested areas.
4. After exposure to ring rot, clean all surfaces of storages and equipment to remove all mud, dirt and debris; use steam or hot water under pressure. **Cleaning alone will not eliminate the bacterium**. Storages and equipment then must be treated with approved chemical disinfectants. Following disease, dispose of all potatoes from the farm.
5. Avoid replanting clean seed potatoes in infested fields for two seasons.

Blackleg and Soft Rot

Symptoms

Tubers from plants with blackleg in the field may show symptoms that vary from slight vascular discoloration of the stem end to jet-black, slightly sunken lesions extending from the stolon about halfway back the tuber (Figure 12). Internal tissues are cream-colored to grayish and are separated from healthy tissues by a dark border (Figure 13). Soft rot infection occurs through wounds or at lenticels and appears as a slightly sunken, brown to tan, water-soaked area. Infected tissues are mushy and sharply separated from healthy areas and can be easily washed away. In early stages, infected tissues are odorless, but as decay develops, they become foul-smelling, with a slimy or stringy consistency.

Cause

Two closely related bacteria: *Erwinia carotovora* pv. *carotovora* (soft rot), and *E. carotovora* pv. *atroseptica* (blackleg).

Development in Field

Blackleg can be carried in seed tubers and become systemic in the plants. The bacteria also can be introduced from cull piles by insects. The bacteria are commonly found in surface water. Bacteria can multiply rapidly during the crop cycle under warm, moist conditions and can infect aerial stems, usually at leaf scars. Soft rot bacteria are extremely common and also reproduce rapidly on warm, moist soils under plant canopies. Infection of tubers occurs through infected stolons or swollen lenticels in moist soils. Much contamination also occurs through fungal infections, frost-damaged tissues or wounds at harvest.

Development in Storage

Tubers harvested at pulp temperatures above 70°F are highly susceptible to breakdown in storage. Free moisture on tuber surfaces resulting from poor air movement or inadequate storage conditions will accelerate rot. Decay can proceed rapidly in storage, and "wet" areas can develop in the pile that drip onto other areas, spreading the infection. Heat and moisture liberated during this process can further adversely affect storage conditions, resulting in accelerated "melt" of the pile.

Control

1. Minimize field blackleg by avoiding over-irrigation and excessive nitrogen application.
2. Avoid bruising tubers at harvest. Avoid harvesting in warm or wet weather. Avoid digging low, wet areas of fields.
3. Grade into storage if significant rot is present.
4. Provide adequate air flow to dry potatoes as quickly as possible. Do not wash prior to storage.
5. Hold potatoes at 50-60°F only long enough to suberize field wounds, then decrease temperatures to 38-40°F. Do not store at chip-stock temperatures (55°F) if significant disease is present.
6. Dry washed potatoes before packing, and use well-ventilated containers. Do not recirculate wash water.
7. Dispose of cull potatoes properly. Do not dump into cull piles.

Tuber Disorders Not Caused by Microorganisms

Internal Necrosis

Symptoms

Symptoms do not occur on vines and are not visible on external tuber surfaces. When cut, affected tubers show tan- to rust-colored irregular patches or flecks throughout the tissues (Figure 14). Flecks usually are clustered off-center in the pith and do not occur in cortical areas near the skin. The flecks remain firm and do not predispose tubers to rot.

Cause

Internal necrosis is not well-understood, but it is believed to be associated with inadequate oxygen for rapidly respiring tissues during active growth under warm, dry conditions.

Development in Field

Internal necrosis becomes more severe as plants approach maturity. It is accentuated by hot, dry weather, especially in light-textured soils.

Development in Storage

Internal symptoms do not increase and may fade somewhat in storage. Affected tubers are not predisposed to any type of breakdown in storage.

Control

1. Cultivars vary widely in sensitivity to internal necrosis.
2. Provide good growing conditions and avoid moisture stress during tuberization.

Shatterbruise and Blackspot

Symptoms

Shatterbruises appear as internal cracks or a series of fissures in the tuber flesh that discolor at the edges (Figure 15). They usually are associated with breaks in the skin but may penetrate deeply or in some cases, be completely internal. Internal blackspots are bluish-black discolored areas, ½-¾ inches in diameter, just under the skin of normal-appearing tubers (Figure 16). The skin usually is unbroken, although in severe cases, the skin over the blackened areas becomes slightly sunken and shriveled.

Cause

Both shatterbruise and blackspot are caused by bruising during harvest and handling.

Development in Field

Four factors determine the amount of bruising at harvest: (1) soil condition, (2) tuber hydration, (3) temperature and (4) harvester operation. Wet, heavy soils are difficult to separate from tubers, and dry clods cause extra bruising. Very turgid potatoes are highly susceptible to shatterbruise but are resistant to blackspot. Dehydrated tubers react oppositely. Effects of temperature on bruising are related to tuber hydration, but in general, damage increases as tuber pulp temperatures decrease below 50°F. This varies not only seasonally, but also with daily harvest times. Improper harvester operation with regard to chain speeds, forward speed and drops or failure to keep chains full can greatly affect bruising.

Development in Storage

Both types of discoloration develop in less than 24 hours after injury but do not enlarge or disappear in storage. Further injury can occur in storage, handling or packing operations. As water is lost during storage, tubers become more susceptible to blackspot. Improper use of bucket loaders and drops exceeding 6 inches on conveyors are primary causes of further injury in handling, especially if tuber pulp temperatures are below 45°F.

Control

1. Try to harvest when soil moisture conditions are favorable and soil temperature is above 50°F. Avoid soil compaction.
2. Operate harvesting equipment to minimize bruising.
3. Reduce all drops to less than 6 inches, and pad deflectors or sharp points on all handling equipment.
4. Maintain storage environment to minimize tuber dehydration.
5. Warm stored potatoes to greater than 50°F pulp temperature before handling.
6. Carefully monitor use of bucket loaders and bin pilers to avoid bruising during handling and packing operations.

Blackheart

Symptoms

External symptoms usually are not visible on affected tubers, although in advanced cases, the skin may have a gray to bluish cast. When cut, the entire central section, or isolated irregular portions of tissue, are jet black (Figure 17). The affected area is firm to slightly spongy and is not separated from healthy tissues by a distinct border.

Cause

Blackheart occurs when insufficient oxygen is available for respiration of stored tubers.

Development in Field

This condition usually does not develop in the field, but it can occur as a result of flooding or extremely high temperatures following vine kill.

Development in Storage

Blackheart can occur in storage at any temperature if sufficient aeration is not available to the pile. It also can occur after prolonged storage near 32°F or when tubers are overheated in transit.

Control

1. Harvest tubers promptly after vine kill in hot weather.
2. Provide optimal storage conditions with forced aeration.
3. Avoid temperatures below 35°F or above 90°F.

Hollow Heart

Symptoms

There are no external symptoms on vines or affected tubers. When cut, internal, lens-shaped to elongate, brown cavities are seen, generally in the center of affected tubers (Figure 18). These vary in size from narrow slits ¼-½ inch long to large cavities 1½-2½ inches long and ½-1 inch deep.

Cause

Hollow heart is associated with the rate of tuber growth and develops as an internal tear or pulling apart of tissues in fast-growing tubers. Anything influencing the rate of tuber growth may affect the development of hollow heart. The tendency toward hollow heart is a varietal characteristic.

Development in Field

Hollow heart begins as an internal tear in tissue in the center or toward the apical end. As the tuber grows, additional tears may occur and connect to form a large cavity. The walls of the cavity initially are white but turn brown with age. Hollow heart most often develops in large tubers. Development of hollow heart is favored by poor plant stands, wide seed-piece spacing, poor tuber set or weather conditions favoring rapid tuber growth.

Development in Storage

Hollow heart does not develop further in storage. It does not predispose tubers to other storage rots.

Control

1. Select a cultivar with a low tendency toward hollow heart.
2. Use large (1½-2 oz) seed pieces or whole "B-size" seed to ensure a higher set.
3. Plant seed pieces at the closest spacing recommended for the cultivar used.
4. Use planting practices that ensure a good stand.
5. Keep fertility at optimal levels. Avoid excessive nitrogen.
6. Irrigate at tuber setting to increase set. Be careful of irrigation during cool periods of rapid tuber growth.
7. Kill vines when tubers have reached optimal size.

PRINCIPLES FOR MANAGING POTATO TUBER DISEASES

During the Growing Season

1. Use certified disease-free seed potatoes.
2. Select proper planting site and practice crop rotation.
3. Use tillage practices that promote good soil structure.
4. Provide good conditions for crop growth.
5. Protect foliage with fungicides.
6. Delay harvest until vines are dead.

At Harvest and in Storage

1. Delay harvest if pulp temperature is below 45°F.
2. Operate harvest machinery to avoid bruising.
3. Avoid harvesting low, wet areas.
4. Grade into storage, if needed.
5. Provide adequate ventilation in storage.
6. Cure tubers 1-2 weeks for wound healing, then store at lower temperatures.
7. Control humidity to minimize tuber dehydration in storage.

During Handling and Packing

1. Warm tubers in storage to 50°F before handling.
2. Adjust handling operations to avoid bruising.
3. Do not recirculate wash water.
4. Dry washed tubers before packing.
5. Use well-ventilated packing containers.

Ohio Cooperative Extension Service
The Ohio State University